From the Transactions of the Royal Society of Canada
Third Series, Section IV, Volume XLIX, 1955

Archean Monazite in Beach Concentrates, Yellowknife Geologic Province, Northwest Territories, Canada

BY

R. E. Folinsbee

Ottawa
Printed for the Royal Society of Canada
1955

TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA
VOLUME XLIX : SERIES III : JUNE, 1955
SECTION FOUR

Archean Monazite in Beach Concentrates, Yellowknife Geologic Province, Northwest Territories, Canada

R. E. FOLINSBEE*

Presented by P. S. WARREN, F.R.S.C.

ABSTRACT

Gneiss-derived monazite occurs as a minor constituent of small, well-sorted beach placers formed from esker sands on the south shore of Yamba Lake, Yellowknife geologic province, Northwest Territories. Magnetite, ilmenite, and almandite garnet are the dominant minerals of the monazite-bearing beach concentrate. Other heavy minerals identified include andalusite, apatite, biotite, brookite, epidote, hornblende, kyanite, olivine, pyroxenes, rutile, scheelite, sphene, sillimanite, spinel, staurolite, tourmaline, and zircon; of these only kyanite has not previously been recognized in rocks of the Yellowknife province. The injection-gneiss or migmatite, source of the monazite, has been assigned to the Archean (2200-2400 million years) on the basis of field relations confirmed by potassium-argon and other age-dating methods. The relation of the gneiss to other rocks of the Yellowknife continental nucleus has been established.

Introduction and General Geology

DURING 1947, in the course of reconnaissance field mapping for the Geological Survey of Canada in the barren grounds 250 miles northeast of Yellowknife, Northwest Territories, sands were collected from esker-derived beach placers. Two of these sands, a monazite-bearing sand from Yamba Lake and a monazite-free sand from Exeter Lake, Lac de Gras map-area, together with the associated rocks, were studied at the University of California, Berkeley, where research facilities were kindly made available to the writer.

W. F. Fahrig, G. A. Vary, G. T. McCallum, A. R. Nielsen, and H. Greiner assisted in collection of samples and field mapping. Professors Turner, Pabst, Gilbert, Verhoogen, and Meyer, of the University of California, and Professor Hutton of Stanford University were most helpful in suggesting solutions to problems in their particular fields. Professor Reynolds and Mr. Lipson of the Department of Physics, University of California, made the potassium-argon age determinations reported in this paper, and Doctors Larsen, Gottfried, Stieff, and Stern of the United States Geological Survey, Washington, contributed data leading to age determinations of the monazite and zircon.

*J. H. Reynolds and J. Lipson, of the Department of Physics, University of California, Berkeley, with whom the writer has been collaborating, deserve full credit for the principal research contribution of this paper—the table of potassium-argon ages.

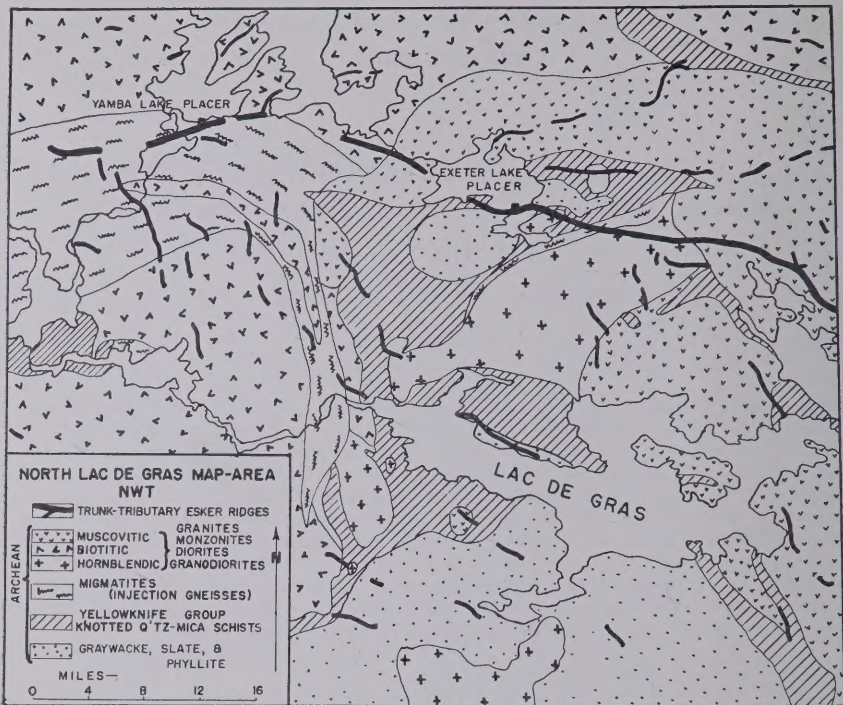

FIGURE 1.—North Lac de Gras map-area, 64°15′ to 65°00′ North, 110°00′ to 112°00′ West, Northwest Territories, Canada.

The map-area (Figure 1) lies almost in the centre of the Yellowknife Geologic Province (Jolliffe, 1948; Gill, 1949). Within the map-area, as throughout the Yellowknife province, the Archean Yellowknife-group graywackes and argillites have been intruded by granitic rocks ranging in composition from hornblende diorites to muscovite pegmatites. In general the hornblendic intrusives appear to be older and the muscovite-bearing intrusives to be younger. Most of the intrusives are probably of Archean age, though there has been much debate as to the extent of the Proterozoic granitic intrusions in the western part of the Canadian Shield (Henderson, 1948). Age dating appears to support the contention of Lord and Barnes (1953) that all of the granitic rocks of this part of the Yellowknife province were intruded during a single period of orogeny which was apparently of very short duration.

The hornblende-bearing intrusives had the least effect on the pelitic and psammatic Yellowknife group sediments; thermal aureoles around these intrusives are small or absent. The biotite granodiorites and muscovite granites have altered the graywackes and argillites to nodular or knotted schists, and to paragneisses. Thermal metamorphic aureoles around the muscovite granites are very prominent, up to eight miles in width.

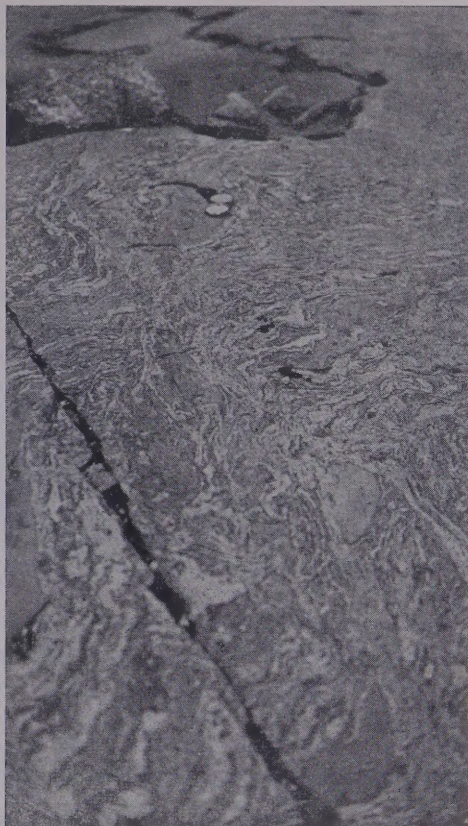

FIGURE 2.—Injection-type migmatite, south of Yamba Lake, Lac de Gras map-area. Geological Survey of Canada photograph.

The paragneisses are migmatitic, strongly foliated rocks developed from deeply buried sediments enveloped by granitic masses. Lenses of light-coloured igneous-like rocks (muscovite and biotite granites) are developed along the foliation planes of the gneiss (Figure 2). They might equally well be attributed to granite injection or to diffusion of granitic constituents from the sediments by anatexis, depending on whether one approaches the migmatite in the mood of a magmatist or a transformationist (Turner and Verhoogen, 1951). On the published map (Folinsbee, 1948) the gneisses are called injection gneisses, but to avoid a controversial point (Alcock, 1949), they will be called migmatites in this paper.

The migmatite, however it was formed, exists as a rock mass covering an area of 500 square miles. The rock is of variable composition, consisting on the average of 40 per cent oligoclase feldspar, 30 per cent quartz, 20 per cent biotite, accessory monazite, rutile and hyacinth cored zircon, with minor muscovite, chlorite and iron oxide as alteration products, and in

places accessory blue cordierite, white fibrous sillimanite, bladed kyanite, black graphite flakes, and almandite garnet crystals suggestive of sedimentary origin. The granite-like lenses, averaging one foot in length and two inches in width are composed mainly of alkalic feldspar, quartz, and muscovite mica. The migmatite is comparable with the Lewisian gneisses of Scotland, as described by Read (1931) and Mackie (1925), and with the Grenville gneisses as described by Engel and Engel (1953).

Glacial and Recent Geology

The map-area lies in the Coppermine ice-drainage basin, where the main ice flow and fluvio-glacial drainage is to the northwest, as indicated by glacial striae, long axes of drumlins, and the trunk and tributary esker-ridge pattern. The principal, or trunk, esker can be traced across the map-area, from north of Lac du Sauvage, south of Exeter and Yamba Lakes. The same esker has been traced from aerial photographs and by field mapping for 320 miles (Wilson, 1939, 1945; Lord and Barnes, 1953). The trunk esker rises as much as 80 feet above local lake level, and in places is 500 feet wide (Figure 3). The esker sands and gravels are of variable size, from boulders to fine sand; though there is usually a high degree of sorting in any one part of the esker.

Winds are predominantly from the northwest, and, in embayments along the south shores of both Yamba and Exeter Lakes, black and purple sands have been washed from the esker sands and gravels by wave action. The high-gravity sand layers are neither thick nor extensive—the ones noted were 50 to 100 feet long, 3 to 10 feet wide, and about 6 inches in thickness. The total tonnage of black sand is small. These beach placers are very well

Figure 3.—Looking east along the trunk esker, Exeter Lake. Black beach placers occur in the cove, centre foreground. Geological Survey of Canada photograph.

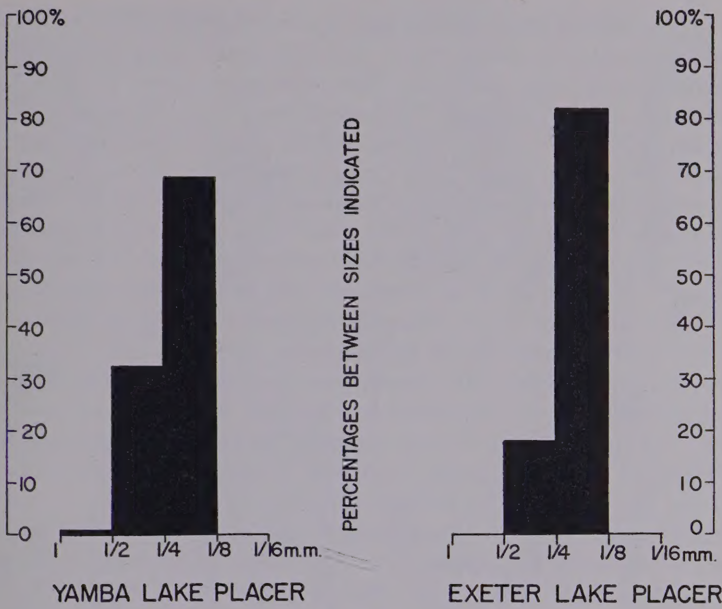

FIGURE 4.—Well-sorted fine and medium grained sands of the beach placer, Lac de Gras map-area, Northwest Territories.

sorted fine sands (Figure 4), and contain less than 1 per cent light contaminants, mostly quartz and feldspars.

Sample Treatment and Mineral Descriptions

Field samples were weighed and screen sized; the dominant size fraction (60-65 mesh) was selected for the most intensive study. This fraction was considered to be representative of the heavy mineral suite, and most suitable for magnetic separation and immersion-mount study. Finer size fractions were examined for such minerals as zircon. With the Frantz isodynamic separator the heavy minerals were separated into fractions of varying magnetic susceptibility (magnetite was first removed with a permanent magnet). These fractions were examined with a binocular microscope, and individual minerals were separated on the basis of colour and other physical properties. Permanent mounts of all separates were made in aroclor (n 1.66). Identity of separate minerals was established using immersion mounts and other tools of the sedimentary petrologist. In general, the methods of study suggested by Hutton were followed (Hutton, 1950, 1952). Only the anomalous optical properties, or those of compositional significance, will be reported in this paper.

Andalusite is fairly abundant in the non-magnetic fraction, occurring as angular grains with characteristic pink to light green pleochroism. The chiastolite variety of andalusite is a common constituent of the metamor-

phosed Yellowknife group pelites; and mauve-coloured crystals of andalusite without carbonaceous inclusions are found in quartz veins in the schists.

Apatite, blue-green under the binocular microscope, is an abundant mineral in the non-magnetic fraction of the beach placers. Index determinations (N_o 1.637, N_e 1.632 $\pm$ 0.002) suggest that these are fluorapatites. Blue-green apatite is a characteristic accessory of the muscovite granites of the eastern part of the map-area, and, as is to be expected, it is more abundant in the Exeter Lake than in the Yamba Lake placers.

Biotite is a minor constituent of the beach placers; since it is an abundant constituent of nearly all the rocks contributing to the esker sands, it is probably rafted out of the eskers during fluvio-glacial sorting, or winnowed out with the light minerals during the placering period.

Brookite grains, light golden-brown in colour, were picked from the non-magnetic fractions and identified on the basis of index and interference figure (Brammal, 1928). Though brookite has not been recognized in thin sections from the rocks of the map-area, it probably occurs as a minor accessory in the granites or gneisses (Mackie, 1928).

Epidote is abundant in the moderately magnetic fractions of the Exeter Lake placers. In the field epidote was observed as an accessory in the granodiorite southeast of Exeter Lake, and with hornblende in the hornblende quartz-diorites south of Exeter Lake; these are undoubtedly the source of the epidote in the Exeter Lake placers. Apparent absence of monazite in the Exeter Lake placers may be explained on the basis of this association, for as Mackie (1928, p. 23) observes, where hornblende or sphene appear in a granitic rock, monazite is never present.

Garnet, of the almandite variety, pink to reddish pink in colour, is an abundant to predominant mineral of the beach concentrate, comprising 35 per cent of the Yamba Lake and 80 per cent of the Exeter Lake placers. Garnet is a very common mineral in the Yellowknife meta-sediments, and occurs also in marginal phases of the biotite granodiorites (Miller, Barnes, and Moore, 1951) and in the muscovite granite pegmatites. Light purplish

---

PLATE I. Typical heavy detrital minerals, Lac de Gras map-area. All figures are at the same magnification ($\times$135) and were drawn from grains immersed in aroclor (n 1.66).

1. Zoned zircon showing very extensive fissuring. Yamba Lake beach sand.
2. Rounded hyacinth core in slightly zoned zircon. Migmatite, Yamba Lake.
3. Euhedral hyacinth core with overgrowth of zircon or malacon. Migmatite, Yamba Lake.
4. Elongate, fluorescent, euhedral zircon with apatite inclusions, from muscovite granite. Prosperous pegmatite, Yellowknife.
5. Euhedral tablet of monazite, moderately fissured. Yamba Lake beach sand.
6. Elongate monazite crystal, showing poor development of cleavage. Yamba Lake beach sand.
7. Rounded monazite crystal. Migmatite, Yamba Lake.
8. Clear yellow monazite, from muscovite granite. Prosperous pegmatite, Yellowknife.
9. Prismatic crystal of tourmaline with rhombohedral terminations. Exeter Lake beach sand.
10. Staurolite crystal showing sieve structure. Exeter Lake beach sand.
11. Bladed crystal of kyanite. Exeter Lake beach sand.

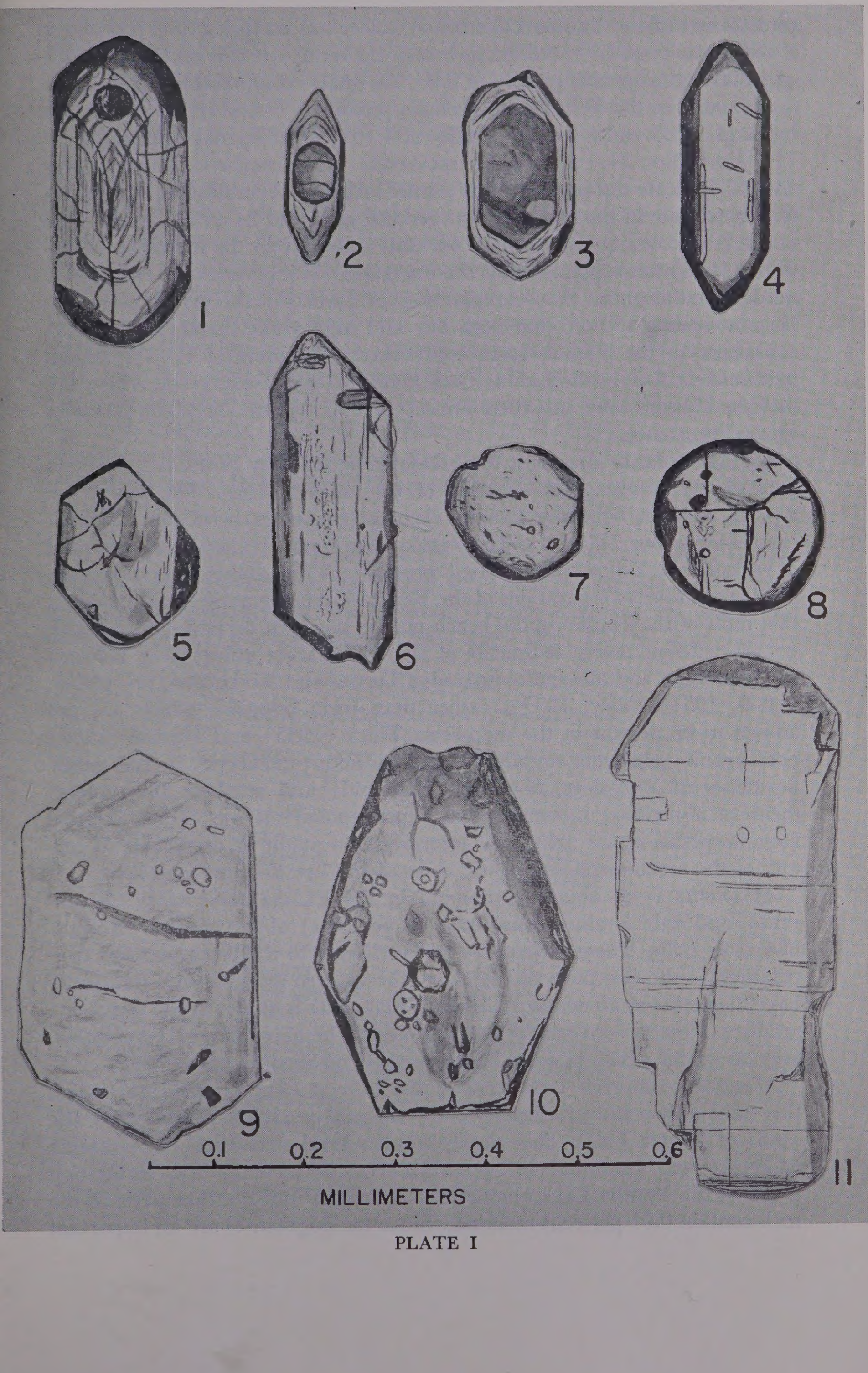

PLATE I

pink garnet of the Yamba Lake beach placer has an index of 1.795 and a specific gravity of 4.17; reddish garnet in the same concentrate has an index of 1.800 and a specific gravity of 3.97. An analysed almandite garnet from a migmatite in the Yellowknife geologic province (Folinsbee, 1941) has an index of 1.798 and a specific gravity of 4.109; its molecular composition is 74.0 almandite, 24.0 pyrope, 1.5 spessartite, 0.5 grossularite. Ford's curves (1915) indicate the purplish pink garnet to be an almandite with considerable spessartite in the molecule; the reddish garnet to be an almandite with about 20 per cent pyrope and 20 per cent andradite in the molecule. Miyashiro (1953) has suggested that the manganese-rich garnets represent lower grade metamorphism than manganese-poor garnets of the pyralspite group. It is interesting to note that both low and high grade metamorphic rocks contribute to the Yamba Lake concentrates (Henderson, 1943), though it is unlikely that in the Lac de Gras map-area the lowest grade schists fall into the chlorite zone, in which Turner (1951) reports abundant accessory spessartite garnet.

Kyanite is fairly abundant to abundant, particularly in the larger screen sizes of the non-magnetic fraction of the beach placers. The grains are typical, angular, light-blue kyanite cleavage fragments, with some carbonaceous inclusions (Plate I). The mineral has not previously been reported in rocks of the Yellowknife geologic province. A few grains of kyanite were recovered in heavy separations of the Yamba Lake migmatite, and it is likely that most of the kyanite in the beach placers has been derived from altered, potash-deficient pelitic sediments of the Yellowknife group lying between the sillimanite and almandite isograds (Turner and Verhoogen, pp. 452–5, 468–9, 1951; Tilley, 1937), rather than from eclogites, which are not known to be present in the map-area. Tilley (1935) and Harker (1954) note kyanite replacing andalusite and cordierite metacrysts in the pelitic hornfelses of Ross-shire, northwest Highlands, and attribute the replacement to a regional metamorphism superimposed on the earlier thermal metamorphism of the area. This interpretation might be applicable to certain of the metamorphosed pelitic rocks of the Lac de Gras map-area.

Magnetite is an abundant mineral in the Yamba Lake sand (40 per cent), and only a minor constituent (3 per cent) of the garnet-rich sands of Exeter Lake. These differences are attributed to the types of rocks contributing to the two parts of the esker; the western granodiorites frequently have magnetite as an accessory mineral, magnetite is absent in the muscovite granites of the eastern part of the map-area. The magnetite is in unaltered, angular grains which in some instances show octahedral crystal faces.

Monazite comprises 1 per cent of the Yamba Lake sample, and makes this sand appreciably radioactive; the mineral is almost absent from the sands of Exeter Lake. This clearly implies local derivation of monazite. Monazite was separated in appreciable quantities from the biotite-rich phase of the Yamba Lake migmatites; recoveries indicate that parts of the rock contain 0.01 per cent monazite. Since the migmatites are an important

rock type in the area, it is likely that they were major contributors to the esker sands of Yamba Lake; it follows that most of the monazite found in the beach placer was probably derived by disintegration of the gneissic migmatite. Monazite is a rare accessory in the granites of the map-area, though a few grains were recovered in separations of muscovite-apatite granites (Plate I).

Monazite in the migmatite occurs as tabular crystals, 0.1 to 0.25 millimeters in diameter (fine sand size); the granular nature of the biotite-rich gneiss, together with this grain size, make the monazite separation and concentration by glacial disintegration, fluvio-glacial sorting, and wave winnowing, a relatively efficient process. The monazite in the beach placers has the same habit, range of grain size, and properties as the monazite in the migmatite. They are low specific gravity monazites (4.91 to 4.94 ± 0.05), with very low refractive indices—alpha 1.776, gamma 1.826 ± 0.003. Optically the most nearly comparable monazites are some from New Zealand and California, reported by Hutton (1950, 1952), though specific gravities of Hutton's monazites are higher (5.21 to 5.26). Unit cell size is normal; Professor Pabst of the University of California reports the following cell dimensions:

a_0 6.76Å, b_0 6.96Å, c_0 6.46Å, beta 103°50′10″; $a_0 : b_0 : c_0 :: 0.971 : 1 : 0.928$

Spectrochemical analysis of the monazite (Table I), though only roughly quantitative, confirms the low thorium content suggested by index and density; with 1.0 per cent silicon rather more than 1.5 per cent thorium

TABLE I

SPECTROCHEMICAL ANALYSIS OF YAMBA LAKE MONAZITE

G. M. Gordon, Spectrographer	
Thorium	1.5%
Lead	0.4%±0.1
Phosphorus	Principal constituent
Silicon	1.0%
Iron	<0.1%
Aluminum	<0.1%
Zirconium	<0.1%
Magnesium	<0.1%
Calcium	<0.1%

Rare earth elements, based on estimates from line intensities without the aid of standards

Large quantities	Nd, La
Medium quantities	Ce, Pr, Sm, Y
Small quantities	Dy
Questionable (low or medium or trace)	Yb, Er
Not detected	Eu, Gd, Ho, Lu, Tb, Tm

would be expected (Hutton, 1952). The rare earth content is comparable with that of monazites analysed by Murata, Rose and Carron (1953).

Monazite is concentrated in the finer screen-size fractions; there is 1 per cent monazite in the 60-65 mesh fraction (0.25 to 0.21 mm.) of the beach placer, 6 per cent monazite in the 100 to 120 mesh fraction (0.15 to 0.125 mm.); similar concentrations were noted in the heavy separations of the Yamba Lake migmatite. The grain size distribution appears to be a reflection of original crystal size, for many of the grains are idiomorphic, and few appear to be crystal fragments (Plate I).

Olivine is a rare constituent of the placers, and is concentrated in the moderately magnetic fraction of the sands, along with monazite. Olivine occurs in certain of the Proterozoic diabase and gabbro dykes of the map-area, and this may be the source of the olivine grains noted in the beach placers.

Pyroxene Group. Orthorhombic pyroxenes (hypersthene and enstatite) and monoclinic pyroxenes (augites) occur in small amounts in the beach placers, particularly those from Exeter Lake. Augite is an important constituent of the diabase and gabbro dykes of the area; Lord and Barnes (1953) have noted a stock-like pyroxenite intrusion into Yellowknife group sediments in the Aylmer Lake map-area to the east. Enstatite has been observed in migmatites similar to the Yamba Lake migmatite elsewhere in the Yellowknife geologic province; occurring in a granulite-facies rock consisting of quartz, almandite garnet, and enstatite interbanded with rocks of the amphibolite facies (Folinsbee, 1941). Hypersthene in the beach placers is readily recognized by its distinct pleochroism, and the suggestion is that hypersthene granulites must be present in the map-area to contribute this mineral to the beach placers. Conditions of metamorphism in the migmatites may approach those under which charnockitic rocks are developed (A. F. Wilson, 1947).

Rutile. A few pleochroic deep-red to reddish-brown striated angular crystals of rutile are present, and readily recognizable, in the non-magnetic fraction of the beach placers. They probably were originally accessory minerals in some of the granitic rocks of the map-area; rutile has also been noted as an accessory in the migmatites south of Yamba Lake.

Scheelite, in small quantities, was recovered from the non-magnetic fraction of the Yamba Lake concentrate; it is essentially absent in Exeter Lake concentrates. Under the ultraviolet lamp (2537 Å) the scheelite fluoresces a cold blue-white, indicating it is the tungsten-rich member of the scheelite-powellite series, as most scheelites in the Archean rocks of Canada appear to be. Index determinations (alpha 1.91, epsilon 1.93 $\pm$ 0.05) confirm the diagnosis. Scheelite occurs in the gold veins of the southern part of the Lac de Gras map-area, and, indeed, is widely distributed in small quantities through gold bearing veins of the Yellowknife geologic province (Lord, 1951). Since scheelite has good placering properties (gravity 6.0) over short distances (its cleavage and softness render it susceptible to attrition),

and is readily recognized with short-wave ultraviolet light, it probably is of value as a mineralization indicator. Presence of scheelite in the Yamba Lake concentrates suggests the presence of scheelite-bearing veins in the sediments southwest of Exeter Lake, an area not easily prospected because of heavy drift cover.

Sillimanite is fairly abundant in the non-magnetic fraction of the beach placers. It occurs in two habits: as fine radiating fibres in a cordierite or biotite matrix, and as rather coarse, elongate, single crystals. Sillimanite occurs in the most highly metamorphosed pelitic schists of the Yellowknife group metasediments, and as a patchily distributed accessory in the Yamba Lake migmatites.

Staurolite is a fairly abundant to minor constituent of the moderately magnetic fraction of the heavy sands, particularly those from Exeter Lake. It exhibits a sieve structure due to numerous inclusions, mostly of quartz, and has a distinct light to deep golden brown pleochroism. Crystal faces are present on a number of the detrital grains suggesting a fairly fine-grained staurolite schist source rock (Plate I). Staurolite develops in the moderately high grade pelitic schists of the Yellowknife group under certain rather special conditions; it is often found where the schists are caught up in granite re-entrants, as east of Exeter Lake. Turner and Verhoogen (1951, pp. 418, 419) suggest that staurolite is confined to rocks of high iron content, and that this chemical dependence accounts for its patchy distribution in pelitic schists of the kyanite subfacies.

Tourmaline grains, pleochroic light-brown to black, are a minor constituent of the moderately magnetic fraction of the beach placers. Many of the grains show prismatic and rhombohedral crystal faces, and are comparable in size and colour to tourmaline crystals developed by boron metasomatism in the pelitic Yellowknife group rocks, particularly in the thermal aureoles found around the muscovite granite. The muscovite granite and related pegmatites commonly have black tourmaline as an accessory mineral.

Zircon. Many types of zircon are present in the finer screen-size non-magnetic fractions of the beach placers; clear zircons, malacons, hyacinths, hyacinth cored, zoned, coloured, fluorescent and non-fluorescent varieties have been noted. Hyacinth has been cited as an Archean type zircon, confined to the ancient gneisses and related granities (Mackie, 1925; Tyler, Marsden, Grout, and Thiel, 1940; Bruce and Jewitt, 1936; Tomita, 1954). Wilson (1954) suggests that age-dating confirms Leith's concept (Leith, 1935) that the terms Archean and Proterozoic should be used for "types of rock, not time," since he and his co-workers find some belts of Archean-type gneisses to be much younger than Proterozoic-type rocks of other parts of the Precambrian shield. Hutton (1950, 1952) points out the ubiquitous distribution of hyacinth, which appears to support Wilson's suggestion that Archean-type gneisses are not confined to the Archeozoic.

Certain facts about the zircons of the map-area have been established. The zircons in the sedimentary phase of the injection gneiss south of Yamba

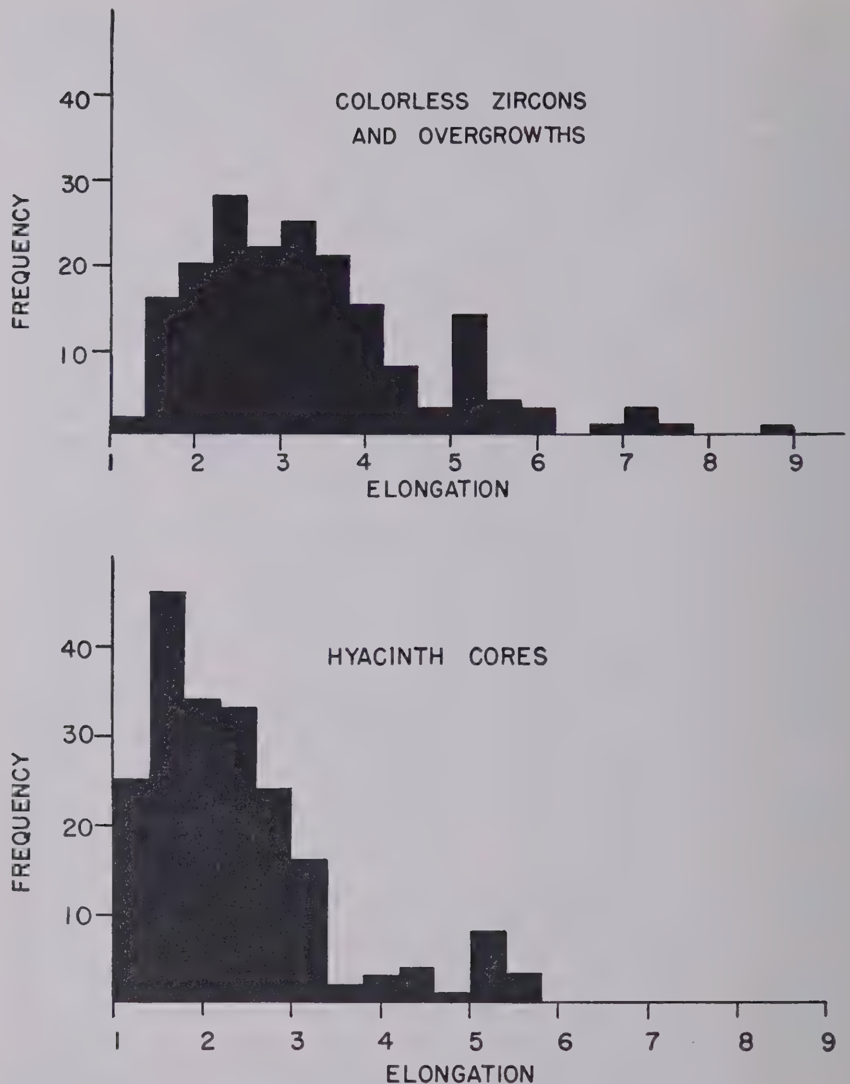

FIGURE 5.—Elongation frequencies of zircons from migmatite, Yamba Lake, Lac de Gras map-area.

Lake are invariably hyacinth cored, in most cases with light-coloured overgrowths, perhaps of malacon (Plate I). The zircon in the early granitic intrusives (the hornblende-biotite diorites) is an extremely elongate, comparatively large, uniformly coloured hyacinth variety. Zircons are rare in the muscovite-apatite granite, those present are of "normal" type—elongate, clear, high index, strongly birefringent, and sharp-angled. Zircons

from the igneous phase of the migmatite are elongate, colourless, zoned, and neither as abundant or large as those from the biotite-rich sedimentary phase. Large zoned zircons are common in the beach placers, their source is probably the granites intruding the migmatites.

If the conclusions of Tyler, Marsden, Grout, and Thiel for the Lake Superior region were applied to the zircons of the Lac de Gras map-area, one would classify the migmatitic paragneiss as an Archean rock, intimately injected by later Archean granites responsible for the malacon overgrowths. The muscovite-granite would be of Killarnean type. This is in general agreement with field observations, but age dating suggests that the time interval between the earliest hornblende diorites and the latest muscovite pegmatites is small, and that the intrusions were probably confined to a single short-lived Archean orogeny.

Zircon of the hyacinth variety, separated from the injection gneiss or migmatite, is non-fluorescent. The normal type zircon, separated from the muscovite-apatite granite, fluoresces a pale golden yellow in short wave ultraviolet light. The muscovite granite is clearly a magmatic type. These observations on fluorescence phenomena are in agreement with those of Foster (1948) for certain zircons from North American granites and those of A. F. Wilson (1950) for the zircons of granites and related gneisses of Central Australia.

The hyacinth-cored zircons show elongation frequencies resembling those reported by Wyatt (1954) for the Moine granulites. Elongation of the hyacinth core is even less than the elongation of the zircon with overgrowths (Figure 5); however, it is the writer's opinion that the roundness of the hyacinth-cored zircons may be in part a function of their rotation during formation of the granulitic migmatite, rather than an entirely inherited sedimentary or aeolian effect, as suggested by Wyatt. Zircons from the Yellowknife hornblende-biotite diorite (K.A. 23–30, Table II) resemble the hyacinth in the migmatite except in elongation. Hyacinth needles in the diorite have elongation indices approaching 32.0, a figure which Poldervaart (1955) notes for zircons from a similar early marginal phase of a granitic pluton. Zircons were insufficient in number in the muscovite granite to provide for a statistical study, but average elongations were of the order of 3, further confirming the magmatic character of this intrusive. In respect to zircon elongations and habits, as well as in the presence of abundant apatite and tourmaline, the muscovite granite resembles the Leinster granite of the north of Ireland as described by Smithson (1932).

Age Dating

Until recently very little was known as to the ages of the rocks in the Yellowknife geologic province; the apparent absence of uraninites has been a bar to application of the accepted uranium-lead methods of age dating. One potassium-argon age has been reported (Shillibeer and Russell, 1954), a determination on perthite from the Moose dyke pegmatite, 2150 million

TABLE II

POTASSIUM-ARGON AGE DATA, YELLOWKNIFE CONTINENTAL NUCLEUS, N.W.T.

Number	Location, latitude & longitude	Type of specimen	A^{40}/K^{40}	Ages using alternative decay constants λ 0.547 R: 0.089*	λ 0.558 R: 0.110**
				m.y.	m.y.
K.A.12	Prosperous Lake map-area 62°40′N, 114°10′W	Muscovite-biotite granite	0.195	*2230*	1950
K.A.31	Walmsley Lake map-area 63°56′N, 108°40′W	Biotite from muscovite-biotite granite	0.266	2650	*2340*
K.A.23	Yellowknife Bay map-area 62°19′N, 114°15′W	Plagioclase from hornblende-biotite-diorite	0.080	1250	1060
K.A.30	Same specimen as K.A.23	Biotite and hornblende from diorite	0.264	2640	*2330*
K.A.33	Courageous Lake map-area 64°16′N, 111°27′W	Quartz and feldspar from rhyolite porphyry	0.162	*2000*	1740
K.A.21	Yellowknife Bay map-area 62°30′N, 114°20′W	Albite from granite boulder in Yellowknife group sediments	0.098	1441	1232
K.A.24	Lac de Gras map-area 64°48′N, 111°41′W	Feldspar and muscovite from injection gneiss	0.118	1634	1405
Tor. 1069A***	Beaulieu River map-area 62°11′N, 112°12′W	Perthite from Moose dyke pegmatite	0.186	*2150*	

*Branching ratio which equates argon ages of potash feldspars with U-Pb age of uraninites from related pegmatites, after Shillibeer and Russell (1954). Wasserburg and Hayden (1955) found applicable almost the same decay constants (λ0.55 and R: 0.085).

**Branching ration given by averaging results of 8 gamma-ray counting experiments reported in the literature is 0.110±0.012.

***Shillibeer and Russell (1954). All other values are those determined by Folinsbee, Lipson, and Reynolds (1955).

years (Table II). This pegmatite is thought to be comparable in age to pegmatitic phases of the muscovite granite of the Lac de Gras map-area. It was pointed out by Shillibeer and Russell that this potassium-argon age is confirmed by the average of 8 galena ages for the Yellowknife geologic province, 2160 million years (Russell, Farquhar, Cumming and Wilson, 1954), though this average galena age has since been increased to 2255 m.y. using a later modification of the galena age equations (Russell and Cumming, 1955). Galenas from gold-bearing quartz-tourmaline veins,

apparently related to the muscovite granite (K.A. 12, Table II), returned ages of 2365, 2340 and 2280 m.y., using the modified age equations. The galena from Horseshoe Island, near the hornblende biotite diorite, returns an age of 2255 m.y. The hornblende-biotite diorite is a marginal phase of the intrusive which returned a young false age when dated by the helium method (Keevil, Jolliffe and Larsen, 1943).

Seven potassium-argon age determinations on rocks and minerals from the Yellowknife continental nucleus have been made at the University of California, Berkeley, using the extremely sensitive apparatus assembled by J. H. Reynolds and J. Lipson, of the Department of Physics (Folinsbee, Lipson, and Reynolds, 1955). J. H. Reynolds made all the spectrometric measurements here reported, J. Lipson did the tedious and exacting argon separations, while the writer made the mineral separations and potassium analyses. All samples used were collected in the field by the writer.

The italicized values are believed to be closest to the true age of the granitic intrusives of the Yellowknife geologic province, and the two determinations on biotite are absolute age determinations in that they are calculated from experimentally determined decay constants. The anomalies are similar to those recently reported by investigators at the Carnegie Institution, Washington (Aldrich, Davis, Tilton, and Wetherill, 1955) and will not be discussed in this paper.

Zircon was separated from the hornblende-biotite diorite (K.A. 23, 30) and a sample forwarded to the United States Geological Survey for a lead-alpha activity age (Larsen, Keevil, and Harrison, 1952). Dr. Gottfried reports an alpha activity of 161 alphas/milligram/hour, a lead content of 69 ppm. and an age of 904 m.y., an anomalously low figure which is, however, in fairly good agreement with the potassium-argon age of the plagioclase fraction of the same rock (K.A. 23, Table II). A cross check on the zircon age was made by the writer using the method suggested by Hurley and Fairbairn (1953) and extended by Holland (1954).

The density of the sample submitted to Gottfried was established as 4.40 ± 0.02, using a Berman balance. From Holland's table this indicates a radiation dosage of 410×10^{13} alphas/milligram. Selected large crystals of zircon, for which the whole crystal emission was believed to be insignificant, gave a broad but symmetrical peak at 2θ 35.31 indicating a radiation dosage of 400×10^{13} alphas/milligram. Small single crystals were measured by Pabst and Quaide, and, probably due to significant whole crystal emission of alpha particles, indicated much smaller radiation dosages. Using Holland's expression for the age, and a 405×10^{13} alphas/milligram average radiation dosage figure, the age of the zircon is 2380 m.y., with a rather high probable error.

Monazite from the Yamba Lake migmatite, thought to be introduced at the time of intrusion of the muscovite-biotite granites, has an alpha activity of 4165 alphas/milligram/hour (Gottfried, personal communication). Gordon (Table I) reports a lead content of 0.4 per cent, $\pm$ 0.1, using

spectrochemical methods. The monazite is roughly 2000 m.y. old, using this data; a chemical analysis for lead by the U.S.G.S. suggests the monazite age to be 2780 m.y. (4035 alphas/milligram/hour, 6190 ppm. Pb), a figure to be used with caution (Stieff and Stern, personal communication).

Both the monazite and zircon appear to be minerals for which a more precise age determination could be made using the lead isotope methods of Holmes (1954) for monazites, and the group from the Carnegie Institution (Aldrich *et al.*, 1955), for zircons.

The most important single conclusion that can be drawn from this data at the present time is that there appears to be no significant age difference between the "older" hornblende biotite diorites (2330 m.y.) and the "younger" muscovite granites (2340 m.y.). These figures are believed to be very close to the actual age of the major period of granitic intrusion in the Yellowknife continental nucleus.

Summary and Conclusions

The esker sands of the Lac de Gras map-area represent the disintegrated, sand-size derivatives of rocks of the Yellowknife group and later granitic intrusives. The two heavy concentrates are typical of those formed, respectively, on granitic and metamorphic terrains; they are indicative of the probable contribution of this portion of the Precambrian shield to later geosynclines. They also afford basic data as to the Precambrian contribution to the glacial deposits of western Canada. In these respects the study may be of interest to sedimentary and glacial geologists working on the western plains.

The marked localization of the esker source material is significant. Wilson (1939) put forward some speculations on this matter, unsupported by field evidence, and these are supported by the present study. The very limited distribution of the monazite-bearing sands is of especial significance. The monazite appears to have been derived almost entirely from a migmatite rich in the radioactive minerals zircon and monazite. No commercial concentrations of radioactive minerals have been reported from rocks of the Yellowknife geologic province, whereas important uranium ore-bodies are located in the adjoining, later, Great Bear and Churchill orogenic provinces. The thorium content of the Yamba Lake migmatite makes this area an immense low grade concentration of radioactive material, which, lying at the root of the Archean mountains, was not subjected to effective concentrating mechanism during the major orogeny.

Age dating suggests that in the Yellowknife geologic province we have a single short-lived series of Archean granite intrusions, which crystallized about 2340 million years ago, and which beautifully illustrate the granite series as developed by Read (1947) and others. It seems likely that the intrusives of the Yellowknife continental nucleus were contemporaneous with the granitic intrusions of the Superior or Keewatin nucleus; a correlation of these two nuclei is indicated.

REFERENCES

ALCOCK, F. J. (1949). A classification of gneisses; Trans. Roy. Soc. Can., 3rd series, vol. 43, Sec. IV, pp. 1–5.

ALDRICH, L. T., DAVIS, G. L., TILTON, G. R. and WETHERILL, G. W. (1955). Comparative radioactive age measurements of igneous rocks near Gunnison, Colorado; abstract from program, 36th Meeting Amer. Geophysical Union, pp. 39–40.

BRAMMALL, A. (1928). Dartmoor detritals: a study in provenance; Proc. Geologists Association, vol. 39, pp. 31–4.

BRUCE, E. L., and JEWITT, W. (1936). Heavy accessories of certain Precambrian intrusives of the Canadian shield; Geol. Mag., vol. 73, pp. 192–213.

ENGEL, A. E. J. and ENGEL, C. G. (1953). Grenville series in the Northwest Adirondack Mountains, New York; Bull. Geol. Soc. Amer., vol. 64, pp. 1013–97.

FOLINSBEE, R. E. (1941). The chemical composition of garnet associated with cordierite; Amer. Min., vol. 26, pp. 50–3.

——— (1948). Las de Gras, Map 977A; Geol. Surv., Canada.

———, LIPSON, J., and REYNOLDS, J. H. (1955). Further applications of the potassium-argon method of age determination; abstract from the Cordilleran Section of the Geological Society of America program, Berkeley, p. 13.

FORD, W. E. (1915). A study of the relations existing between the chemical, optical and other physical properties of the members of the garnet group; Amer. Jour. Sci., 4th series, vol. 40, pp. 33–49.

FOSTER, W. R. (1948). Useful aspects of the fluorescence of accessory mineral zircon; Amer. Min., vol. 33, pp. 724–35.

GILL, J. E. (1949). Natural divisions of the Canadian Shield; Trans. Roy. Soc. Can., 3rd series, vol. 43, Sec. IV, p. 61.

HARKER, R. I. (1954). Further data on the petrology of the pelitic hornfelses of the Carn Chuinneag-Inchbae region, Ross-shire, with special reference to the status of almandine; Geol. Mag., vol. 91, no. 6.

HENDERSON, J. F. (1943). Structure and metamorphism of Early Precambrian rocks between Gordon and Great Slave Lakes, Northwest Territories; Amer. Jour. Sci., 4th series, vol. 241, pp. 430–46.

——— (1948). Extent of Proterozoic granitic intrusions in the western part of the Canadian Shield; Trans. Roy. Soc. Can., 3rd series, vol. 42, Sec. IV, pp. 41–54.

HOLLAND, H. D. (1954). Radiation damage and its use in age determination; in Nuclear Geology, pp. 175–80.

HOLMES, A. (1954). The oldest dated minerals of the Rhodesian shield; Nature, vol. 173, pp. 612–14.

HURLEY, P. M., and FAIRBAIRN, H. W. (1953). Radiation damage in zircon: a possible age method; Bull. Geol. Soc. Amer., vol. 64, pp. 659–74.

HUTTON, C. O. (1950). Studies of heavy detrital minerals; Bull. Geol. Soc. Amer., vol. 61, pp. 635–716.

——— (1952). Accessory mineral studies of some California beach sands; U.S. Atomic Energy Com., R.M.O. 981.

JOLLIFFE, A. W. (1948). The north-western part of the Canadian Shield; International Geol. Congress, Report of 18th Session, Great Britain, pp. 141–9.

KEEVIL, N. B., JOLLIFFE, A. W. and LARSEN, E. S. (1942). Distribution of helium and radioactivity in rocks. Part IV. Helium age investigations of diabase and granodiorites from Yellowknife, Northwest Territories, Canada; Amer. Jour. Sci., 4th series, vol. 240, pp. 831–46.

LARSEN, E. S., KEEVIL, N. B., and HARRISON, H. C. (1952). Method for determining the age of igneous rocks using the accessory minerals; Bull. Geol. Soc. Amer., vol. 63, pp. 1045–52.

LEITH, C. K., LUND, R. J., and LEITH, A. (1935). Precambrian rocks of the Lake Superior region; U.S. Geol. Surv., Prof. Paper 184.

LORD, C. S. (1951). Mineral industry of the Northwest Territories; Geol. Surv., Canada, Memoir 261.

LORD, C. S. and BARNES, F. Q. (1953). Aylmer Lake, Map 1031A; Geol. Surv., Canada.

MACKIE, W. (1925). The source of the purple zircons in the sedimentary rocks of Scotland; Trans. Edinburgh Geol. Soc., vol. 11, pp. 200–13.

——— (1928). The heavier accessory minerals in the granites of Scotland; *ibid.*, vol. 12, Part I, pp. 22–40.

MILLER, M. L., BARNES, F. Q., and MOORE, J. C. G. (1951). Carp Lakes, N.W.T.; Preliminary Map 51–8, Geol. Surv., Canada.

MIYASHIRO, A. (1953). Calcium-poor garnet in relation to metamorphism; Geochimica et Cosmochimica Acta, vol. 4, pp. 179–208.

MURATA, K. J., ROSE, H. J., and CARRON, M. K. (1953). Systematic variation of rare earths in monazite; Geochimica et Cosmochimica Acta, vol. 4, pp. 292–300.

POLDERVAART, A. (1955). Zircons in the granite series; abstract from program, 36th Annual Meeting, Amer. Geophysical Union, p. 33.

READ, H. H. (1931). The geology of central Sutherland; Geol. Surv., Scotland, Memoir, pp. 88–164.

———, BUDDINGTON, A. F., GROUT, F. F., GOODSPEED, G. E., BOWEN, N. L. (1947). Origin of granite; Geol. Soc. Amer., Memoir 28.

RUSSELL, R. D. and CUMMING, G. L. (1955). Lead isotope abundances; abstract from program, 36th Annual Meeting, Amer. Geophysical Union, p. 38.

———, FARQUHAR, R. M., CUMMING, G. L., and WILSON, J. T. (1954). Dating galenas by means of their isotopic constitutions; Trans. Amer. Geophysical Union, vol. 35, pp. 301–9.

SHILLIBEER, H. A. and RUSSELL, R. D. (1954). The potassium-argon method of geological age determination; Can. Jour. Physics, vol. 32, pp. 681–93.

SMITHSON, F. (1932). The petrography of the northern portion of the Leinster granite; Geol. Mag., vol. 69, pp. 465–74.

TILLEY, C. E. (1935). The role of kyanite in the "hornfels zone" of the Carn Chuinneag granite (Ross-shire), Scotland; Min. Magazine, vol. 24, pp. 92–7.

——— (1937). The paragenesis of the kyanite-amphibolites; *ibid.*, vol. 24, pp. 555–67.

TOMITA, T. (1954). Geologic significance of the color of granite zircon, and the discovery of the Pre-Cambrian in Japan; Memoirs of the Faculty of Science, Kyushu University, Series D, vol. 4, Geology, pp. 135–61.

TURNER, F. J. and VERHOOGEN, J. (1951). Igneous and metamorphic petrology, pp. 258–307, 471–2. McGraw-Hill.

TYLER, S. A., MARSDEN, R. W., GROUT, F. F., and THIEL, G. A. (1940). Studies of the Lake Superior Precambrian by accessory mineral methods; Bull. Geol. Soc. Amer., vol. 51, pp. 1429–1538.

WASSERBURG, G. J. and HAYDEN, R. J. (1955). A^{40}-K^{40} dating; Geochimica et Cosmochimica Acta, vol. 5, pp. 51–60.

WILSON, A. F. (1947). Charnockites and associated rocks of northwest South Australia; Trans. Roy. Soc. Australia, vol. 71 (2), pp. 195–211.

——— (1950). Fluorescent felspar and zircon as petrological aids; Min. Magazine, vol. 29, pp. 225–33.

WILSON, J. T. (1939). Eskers northeast of Great Slave Lake; Trans. Roy. Soc. Can., 3rd series, vol. 33, Sec. IV, pp. 119–29.

——— (1945). Further eskers north of Great Slave Lake; *ibid.*, vol. 39, Sec. IV, pp. 151–3.

———, FARQUHAR, R. M., GRETENER, P., RUSSELL, R. D., and SHILLIBEER, H. A. (1954). Estimates of age for some African minerals; Nature, vol. 174: pp. 1006–7.

WYATT, M. (1954). Zircons as provenance indicators; Amer. Min., vol. 39, pp. 983–90.

DATE LOANED	BORROWER'S NAME	DATE DUE
Due Cam JUN 17 '96		
DUE CAM SEP 15 '9		
JUN 0 4 RETURN		

Printed in Canada